PB-215 082

EQUALIZATION OF LIQUID WASTES

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Newark College of Engineering
Newark, New Jersey

1965

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WP-41

PB 215 082

EQUALIZATION OF LIQUID WASTES

FINAL PROGRESS REPORT

on

RESEARCH GRANT WP-41

sponsored by

U.S. PUBLIC HEALTH SERVICE
Division of Water Supply and Pollution Control
Washington 25, D. C.

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ACKNOWLEDGEMENTS

Preliminary studies for this project were supported by the Newark College of Engineering Research Foundation.

Mr. Christian Hoffman, Assistant Instructor in Civil Engineering, aided in developing the model and test procedures. The tests were conducted by Mr. Ronald Kunz, undergraduate, and later, graduate Research Assistant.

ABSTRACT

The operation of waste treatment plants is often complicated by an intermittent flow of toxic materials, known as shock loads, usually from industrial sources. These shock loads, containing high concentrations of pollutants, may upset biological activity, fail to be adequately treated, or disrupt treatment programs. Intermittent discharges may cause such wide fluctuations in concentrations at the plant that adequate treatment may not be obtained. The response of manual, or even automatic, equipment is often not adequate for these fluctuations.

This problem of shock loads has been reported in a number of cases. The solution usually involves some type of holding tank, in which an attempt is made to reduce the extremes of concentration. This process is relatively simple in batch operation where wastes are accumulated and the contents mixed. However, no simple solution seems apparent in continuous flow units where both sedimentation - and mixing-type units are used.

An efficient sedimentation tank would yield an effluent tracer pattern which increases to a peak and then decreases. A continuous flow mixing tank has a tracer pattern which starts at a maximum value and then decays. If equalization is viewed as an attempt to produce a constant effluent concentration, then neither sedimentation basins nor mixing tanks are adequate. That they produce some degree of equalization is related to their inefficiency for their primary purpose.

An ideal equalization tank is defined herein as one which would, following a shock load, produce a uniform effluent concentration. Since the

mean of the effluent tracer pattern represents the theoretical detention time, the effluent pattern sought is horizontal for twice the theoretical detention time. This pattern can be produced in a tank which is shaped to cause half the material to be removed before the theoretical detention time. It is shown that a triangular shape of constant depth with continuous discharge would produce ideal equalization.

A triangular tank was constructed as a test model and flow-through studies were made using fluorescein dye evaluated with a colorimeter. These studies demonstrate that the proposed shape will produce an effluent pattern which approaches the desired result.. The benefits of shape out-weigh the effects of inlet distribution, outlets, etc., and could result in a practical solution for the problem of equalization.

INTRODUCTION

Man has been dominated by the location and quality of water since his appearance on earth. The first settlements were made near water because it is necessary to sustain life. Some of these early settlements were near large bodies of water which later were used for transportation purposes. As civilization developed water was controlled by man for his purposes. Canals were built in China for transportation and in Rome aqueducts were constructed for municipal water supply. These uses of water became widespread by the time of the Industrial Revolution. Today, huge dams, reservoirs, canals, and water treatment and supply systems are used to deliver water of specified quality and quantity to desired locations.

One very important use of water is for the carriage of the waste material of society. This use was recognized early by man as evidenced by many sewers which were built about the same time as the ancient aqueducts.

The water carriage of wastes is used almost exclusively today in urban areas of the United States. Many of the streams which receive these wastes are subsequently used for water supply. During the nineteenth centry, it was recognized that such use of a stream is a potential means for disease transmission. This is especially true in highly populated areas where the dilution and self-purification is not sufficient for the wastes discharged into a stream.

In addition to the carriage of domestic wastes, streams must carry ever-increasing amounts of waste water from industry. Industrial wastes often contain toxic chemicals or taste-and odor-producing materials which may

impair the quality of water for further use. The industrial waste problem is compounded since industry stimulates further population in an area, and a greater domestic waste load. The problems of stream pollution have become extremely important in protection of the public health since many streams serve a dual function; that of water supply and waste-water disposal. Nuisance conditions resulting from odors and colors must be removed in addition to disease-transmitting agents. The preservation of natural resources and the aesthetic values of clean streams must also be considered.

The treatment of domestic and industrial wastes has reached a high degree of technial development. However, there are a number of problems which still exist. One such problem results where the wastes entering a treatment plant, or some unit of a treatment plant, are not of constant quantity or quality. For example, in industrail treatment the loading to the plant may be a series of intermittent discharges resulting from the completion of various manufacturing operations. A similar condition may exist where industrail wastes are suddenly discharged into a municipal sewer. These intermittent discharges often contain very high concentrations of pollutants. If these high, varying concentrations were discharged directly to a treatment plant it would be forced to operate under widely varying conditions. Plant equipment would require continuous attention or automatic control. Even with automatic control, the units are not always able to respond quickly enough to radical changes in concentrations. Under such loading conditions all equipment would have to be designed to operate under maximum loading conditions.

These intermittent high concentrations, or "shock loads" as they are called in waste treatment, may render units inoperative or inefficient.

Biological treatment is especially sensitive to shock loads. When a shock load of toxic material is discharged to a stream, the harmful effect may be much greater than it would be if the same amount of toxic material were discharged over a period of time. In general, it is desirable that the concentration of pollutional materials be nearly constant at all times for discharge to treatment plants, certain units, or a stream.

Shock loads are often reduced in practice by the use of holding tanks. These tanks provide a detention period which is to permit the equalization of fluctuations in flow or in concentration. The process is known as equalization, with the terms "averaging" and "compositing" used in the same sense.

Equalization may be accomplished in batch treatment or in continuous flow units. In batch treatment the wastes and shock loads are accumulated in a tank, the contents are mixed, and then chemicals are added for treatment. More than one tank is usually provided so that while one is in the treatment stage the other may be used for equalizing. This type of treatment is satisfactory for small plants or small volumes of concentrated wastes; but, continuous treatment is more desirable for large volumes. In continuous treatment some type of tank must be provided to detain and mix the wastes which are received by the plant during a time interval. Properly designed tanks should equalize the wastes and permit the plant to operate on materials with a nearly constant concentration.

Many treatment plants have been equipped with units for equalizing waste concentrations. While these units vary in arrangement and effectiveness, one factor usually has been common to all past designs. The wastes enter at one end of a tank or lagoon and discharge from the opposite end after a certain

dentention period. This flow pattern resembles that of a sedimentation tank.

The purpose of sedimentation is to remove suspended particles by producing nearly quiescent conditions. Ideal settling conditions would occur if a liquid moved through a tank with a uniform horizontal velocity in the cross-section (6)* Mixing would not occur in an "ideal" settling tank and in practice efforts are directed toward minimizing short-circuiting and mixing. Conversely, some mixing is necessary in equalization in order to disperse a small volume of concentrated waste into a larger volume of liquid.

OBJECT OF INVESTIGATION:

It would appear that the hydraulic design of an equalization tank should be different from a settling tank. The degree of success in equalization units which have been designed after usual sedimentation practice may be attributed to the impossibility of achieving ideal settling conditions. It seems reasonable to assume that a more rational approach to the design of equalization tanks could be found.

The purpose of this investigation is to develop a rational approach to the design of equalization tanks which could be followed in designing practical units.

SCOPE OF INVESTIGATION

Consideration is given in this investigation to those conditions which are likely to be applicable to many equalization situations.

*Numerials in parenthesis - thus: (6) - refer to corresponding items in the Bibliography.

In this work the settling of particles during equalization will not be considered. A further investigation to consider settling may be desirable; but, only equalization is considered herein.

It has been mentioned that equalization may involve batch or continuous units. Continuous flow units are used in more and in larger plants and, therefore, are the only units considered in this work.

The required energy for mixing in equalizing tanks can be provided mechanically or hydraulically. Mechanical mixers are best suited for batch operations and the most satisfactory types are rotating impellers of the marine or radial-flow type (37,8). Hydraulic methods of mixing (head loss) should prove more satisfactory and economical for large, continuous-flow plants. A simple earth or concrete tank with no moving parts should be most satisfactory. Therefore, only hydraulic methods are considered in this investigation.

REVIEW OF THE LITERATURE ON EQUALIZATION

The problem resulting from the sudden introduction of highly contaminated wastes, or shock loads, into a stream or a treatment plant has received considerable discussion in the literature. These discussions indicate the harmful effects of shock loads and demonstrate the need for equalization in many cases. Further discussions describe specific installations which were designed to accomplish equalization. Since the analysis presented herein depends on a knowledge of work previously reported, it appears prudent to present a brief summary of this work. The summary includes a discussion of shock loads and the consequent need for equalization. Lagoons, holding and mixing tanks, settling basins and other existing methods of equalization are also reviewed.

SHOCK LOADS:

The harmful effect of shock loads of toxic materials on the operation of biological treatment processes has been pointed out by Geyer (16), Babbitt (3) and others (28, 41, 43). Fair and Geyer (14) report that biological treatment processes have a marked ability to adjust to toxic wastes when the waste concentration is raised gradually over a long period of time. However, they indicate that shock loads may be fatal to organisms. For example, De Lano (10) reported about an industrial user who asked permission to discharge 700 gallons of spent copper cyanide. Arrangements were made to slowly discharge it to the treatment plant with a high dilution factor. Thirty-six hours later the plant efficiency had been reduced from 80 to 56 percent BOD removal. The Sludge Volume Index increased each day after this until it was necessary to

unload the activated sludge and start the process anew.

Wakefield, Kelso and O'Neil (42) report that shock loads of citrus waste caused problems in primary treatment. They report that discharge of citrus waste without prior planning can be quite disastrous. In one case press liquor discharged to a primary treatment plant so upset the digestion tanks that they had to be taken out of service and cleaned. In other cases the decomposition of citrus solids and the fermentation of dissolved sugars caused the primary treatment tank to become anaerobic, resulting in severe odors and decreased efficiency. Sawyer (38) has discussed problems in sludge digestion caused by toxic materials.

Shock loads must also be considered by the designer who should select the size of chemical feeders and related equipment according to variations in concentration and flow (32). He should recognize that the sudden entrance of a slug could upset control systems.

The need for equalization in the treatment of industrial wastes has been discussed by Gurnham (18). He indicated that the use of equalization techniques is beneficial for overcoming extreme fluctuations in flow rate and concentrations in continuous-flow treatment. He further indicated that equalization is useful ahead of activated sludge and trickling filter plants in order to prevent upset by shock loads. He pointed out that equalization is especially desirable in automatic control operations of pH adjustment, chlorination, and other treatments. With raw wastes showing wide variations in acidity or alkalinity, Gurnham feels that equalization tanks even out these fluctuations and permit more effective instrumentation. An excerpt from a more recent study by Gurnham (17) shows the importance of considering shock loads.

> "One of the frequent causes of poor operation of the sewage treatment plant is the occurrence of shock loading in the incoming sewage. Industry must recognize that sewage treatment processes are geared to continuous 24 hour, 7-day operation, and that the more nearly uniform the raw material entering the plant, the smoother the operation of the plant and the better the quality of its product. Most treatment plant operations have a considerable capacity to absorb fluctuations in raw-material -- this is necessary because even domestic sewage flow varies in volume and concentration from hour to hour. But this leveling-out ability of the plant must not be abused by shock loads beyond its capacity. This is one reason that many communities provide separate strom sewers -- the sudden rush of relatively pure water from a quick rainstorm is itself a shock to the treatment plant. Consider then the unbalance that may result if the shock discharge consists of acids or chemicals, sediment, or high temperature, rather than just a high rate of flow."

With the need for equalization established in the mind of many authors, attention has logically been directed at methods of accomplishing it. Sewers have been thought to provide a degree to equalization (17); however, the work of Rudolfs (36) may demonstrate otherwise. He showed that very little equalization took place when acid wastes were introduced into a sewer 3,000 feet long. From this study he indicated that additional equalization may be necessary with the introduction of industrial wastes into municipal sewers. For this reason, further discussion is presented herein concerning in-plant methods of providing equalization.

LAGOONS:

A lagoon may partially equalize fluctuations in flow rate and waste concentration, either in raw wastes or in partially treated effluents (18). The degree of equalization achieved is a function of detention time in the lagoon and degree of mixing of retained liquids. In some installations, lagoon

capacity is sufficient for the entire waste from a season's operation or large enough to retain the waste produced between successive periods of high water in the receiving stream.

Short-circuiting of flow through a lagoon would decrease the capacity for equalization. An example of this would be in an old lagoon nearly filled with sediment, where the liquid forms a small stream crossing the lagoon in a definite channel. In spite of a number of limitations, lagoons and holding tanks are widely used in practice to equalize flows and reduce shock loads. This process is often referred to as "compositing" or "averaging".

Bayuk (5) reported on the design of a 360,000 gallon earth lagoon for equalization of both flows and waste concentrations from a chemical plant. The lagoon provides a twelve-hour detention period prior to the treatment. It was expected that this would accomplish a satisfactory degree of equalization which would ensure proper treatment.

Kallin (22) has indicated that cyanide wastes from the Ford Company Plating Plants on Lake Erie are to be disposed of by holding to blend the wastes and then by dilution. He reports that the holding tanks are expected to provide a homogenous waste.

King has described the compositing basins at the Bound Brook, New Jersey, plant of the American Cyanamid Company (24). In these units the flows from diverse chemical manufacturing operations are brought together and the basin provides opportunity for interaction of different types of wastes. Some results claimed by King for the process include: the reduction of shock loads, self-neutralization, color equalization, settling of precipitates, salt formation, and some destruction of B. coli.

While lagoons have been reported to provide some degree of equalization they are usually large and lack proper plant control. Smaller tanks equipped with mixing devices are, therefore quite common.

HOLDING AND MIXING TANKS:

At the Allison Division of the General Motors Corporation (7) wastes from the various departments are segregated, delivered to the plant, and equalized in 5000 gallon batches before entering the treatment units. Two holding tanks, each having a capacity of one-half million gallons, are used to equalize the intermittent and irregular delivery of strong wastes to the treatment plant. The tanks are equipped with a system of air jets for mixing the contents. Oil launders are used for periodic removal of the accumulated oil scum by raising the liquid level.

Milne (31) reported that holding tanks are being used successfully by the General Motors Corporation. He stated that treatment facilities previously located in various manufacturing plants have been replaced by a large centrally located waste treatment plant.

A similar plant at Pontiac Motors, described by D'Orazio (12), is provided with two large holding tanks which are used for storage as well as treatment of the metallic acid waste. Each is a 520,000 gallon steel tank lined with karoseal and provided with an agitator.

The General Electric Plant in Louisville, Kentucky, described by Watson and Fair (44), employs a mechanically-mixed tank to equalize the varied wastes from the manufacture of appliances. The treatment plant is equipped with a circular concrete basin sixty feet in diameter, which has a capacity

of 250,00 gallons. This tank has a center agitator to mix the wastes. The influent is introduced at the center of the basin and flows radially to an overflow weir at the periphery of the structure. This tank effectively equalizes the varied wastes before further treatment.

Rudolfs (36) described an installation for pre-treatment of acid chemical wastes at the Rahway Valley Joint Meeting Sewage Treatment Plant. This installation has a tank in which equalization and neutralization of acids are accomplished. The tank, discussed by Rudolfs and Millar (35), has a volume of 21,000 gallons and a detention time of about one hour. Three wooden-gate agitators are spaced equally along the center line of a rectangular tank. The influent enters at the bottom of the tank, flows past the agitators, and discharges over a weir at the opposite end of the tank.

Frame (15) reports that the Trafalgar refinery uses a rectangular pit large enough to hold one day's flow of waste. He describes the basin as follows:

> "Three sets of pipes enter the equalization basin: one carries steam; another carries air; and the third brings in the effluent from the separator tank. This third pipe is perforated and centrally located so that it distributes the incoming waste down the full length of the basin. Air is bubbled in to aid oxidation and insure thorough mixing. Steam pipes prevent the effluent from freezing in the winter. Provision is made to skim off any free oil that may have escaped the separator tanks, and there is a spare equalization basin in case the flow becomes too great for one basin to handle."

Two equalization tanks at American Cyanamide's Bridgeville, Pennsylvania, plant were designed for two hours detention at an average daily flow of 900 gpm.

Loveless and Atkins (27) report that each 54,000 gallon tank is 26 feet in diameter with 13.5 feet of effective water depth. Tank turnover with a

10 HP impeller was estimated at 30,000 gpm or approximately once every two minutes. The tanks are expected to produce a homogenous mixture with respect to pH and nonstratified contents with respect to solids which do not settle faster than one foot per minute. Other pumping systems have been reported (13, 23).

SETTLING BASINS:

Dickerson et al (11) have reported on the use of a lagoon and two settling tanks for treating shock loads. Their discussion of plant operation follows:

> "The lagoon was installed primarily for storage of wastes that could not be handled at the waste treatment plant. Two wood tanks were installed for sedimentation of the precipitated sludge and equalization of the wastes. Experience indicated that these tanks were not always effective in their equalizing role. But when the flow was changed to pass through the lagoon before entering the tanks, the BOD values became more constant and the treatment plant more efficient. The lagoon is not always necessary. In fact, it has been some months since it was last used. But, if stronger-than-normal wastes appear, or if the de-emulsification process should fail, the only way to prevent a shutdown of operations is by lagoon storage."

Horne et al (19) and Horne and Inaca (20), have discussed the use of settling basins for equalization at the Stonewall Plant of Merck and Company, Inc. Their description of the plant and conclusion follow:

> "Liquid chemical wastes from the grit removal unit flow into a circular equalization basin. This basin has a diameter of 60', a sidewall depth of 15', and its 315,000 gal. capacity retains the waste for five to six hours. During this time additional sedimentation, acid and alkaline equalization, and removal of immiscibles occurs. The floating immiscibles are continuously removed by a mechanical skimmer and

periodically burned. The settled solids are continuously raked to a sump and pumped to the stabilization facilities. The effluent from the equalization basin is neutralized to a final pH of seven to eight by automatic addition of acid or base at the effluent weir, and thereafter joins the sanitary waste effluent from the primary treatment unit. From here the combined streams proceed to secondary treatment.

It is recognized that the functions of equalization and sedimentation cannot be effectively performed concurrently. Therefore, a new 60-ft. diameter sedimentation basin is being constructed. The present equalization-sedimentation basin will be altered to provide agitation and variable level for maximum equalizing and hydraulic surge control."

OTHER METHODS:

Clinton (9) reported that activated sludge plants can be designed for industrial wastes if sufficient pre-aeration is provided. For cases of heavy shock loads he recommends that chemical precipitation be applied using the pre-aeration basin as a flocculator. Modified aeration tanks have also been used for equalization (4).

Hosman and Keating (21) determined that the best method for handling the waste problem at the IBM Plant, Endicott, New York, was to concentrate dilute solutions with a system of ion exchangers. The concentrated wastes were then subjected to batch treatment.

The use of an idle clarifier to partially alleviate spills has resulted in satisfactory plant operation as reported by Rhame (34).

Trickling filters were used to handle shock loads at the Rohm and Haas Company. Majewski et al (28) have described the construction and performance of the filters.

Kohlschutter (26) has suggested a theoretical approach for a hydraulic mixing process. He has proposed various shapes of basins to accomplish mixing and has described the mixing which should occur in each tank.

FLOW-THROUGH CONSIDERATIONS

The review of the literature indicates that both mixing - and settling - type tanks have been used in an attempt to accomplish equalization. For this reason, flow-through characteristics of these types of tanks are considered and compared with the characteristics necessary for equalization. The following discussion, presents a review of the principles of flow through curves and is limited to continuous-flow tanks.

FLOW-THROUGH CURVES:

An apprasial of flow characteristics of continuous-flow tanks is frequently made by introducing a slug of dye into the inlet of a tank (25). The dye becomes dispersed into the fluid and moves through the tank in the same fashion as the liquid. One can observe the dye movements for a qualitative study of the hydraulics of the tank. A quantitative evaluation is accomplished by measuring the dye concentrations in the tank effluent at various times. This data can be used to determine the average time that any portion of the liquid remains in the tank.

It is common to present the flow-through curve in terms of a dimensionless plot. The measured effluent concentration, c, obtained at time, t, is usually divided by a mean concentration, Co. Co is defined as the mass of the tracer, W, divided by the volume of the tank, V. The ordinate to a flow-through curve is then c/C_o. The abscissa, t, is made dimensionless by dividing it by the theoretical detention time, T, which is defined as the tank volume, V, divided by the flow rate, Q. Using the coordinates c/Co and t/T, tanks of

various design can be compared. A typical flow-through curve is presented in Fig. 1 (a).

The dimensionless flow-through curve has some definite properties. Consider, for example, the area under the curve of Fig. 1 (a).

$$A = \frac{1}{C_o T} \int_0^\infty c\,dt = \frac{Q}{C_o V} \int_0^\infty c\,dt \qquad (1)$$

but

$$Q \int_0^\infty c\,dt = W \qquad (2)$$

and

$$A = \frac{W}{C_o V} = \frac{C_o}{C_o} = 1 \qquad (3)$$

Thus the area is unity and represents the time distribution of the entire slug in the effluent. Of course, an observed curve may deviate from this due to loss of tracer due to adsorption, fading or decoy. Dead spaces in a tank would also produce an area less than one.

The centroid of area also has an important characteristic. The centroid, t_c, is (25):

$$t_c = \frac{1}{T} \int_0^\infty \frac{ct\,dt}{c\,dt} \qquad (4)$$

If the tracer is completely mixed with the fluid, the fraction of tracer, dW/w; which passes in time, t , equals dQ/Q. Then

$$dQ = Q\,\frac{dW}{W} = Q\,\frac{cQ\,dt}{W} = \frac{Q^2}{W}\,c\,dt \qquad (5)$$

and

$$c\,dt = \frac{W\,dQ}{Q^2} \qquad (6)$$

$$t_c = \frac{1}{T} \frac{\int_0^\infty \frac{W}{Q^2}\, t\,dQ}{\int_0^\infty \frac{W}{Q^2}\, dQ} = \frac{1}{T} \frac{\int_0^\infty t\,dQ}{\int_0^\infty dQ} = \frac{1}{TQ} \int_0^\infty t\,dQ \qquad (7)$$

but
$$dQ = v\,dA, \; v = \frac{L}{t}, \quad \text{so} \quad dQ = \frac{L}{t}\,dA \qquad (8)$$

$$t_c = \frac{1}{TQ} \int_0^\infty t \frac{L}{t}\, dA = \frac{L}{TQ} \int_0^\infty dA = \frac{LA}{TQ} = \frac{V}{TQ} = \frac{T}{T} = 1 \qquad (9)$$

This demonstrates that the centroid represents the theoretical detention period. The deviation of the mode from the centroid in an actual tank can represent and short-circuiting other non-uniform flow conditions.

MIXING:

One extreme of a flow-through curve is produced in an ideal mixing tank. Here enough violent agitation is produced so that influent slugs of waste can be considered to be completely and instantaneously mixed with the entire volume of liquid in the tank. In this case the average concentration, Co, is immediately produced in the effluent and then decreases with time as clear influent continues to enter the tank. The equation for this flow-through curve, shown in Fig. 1 (b), is:

$$\frac{c}{C_o} = e^{-t/T}$$

It should be noted that the highest effluent concentration is produced immediately upon injection of the slug.

The op osite of complete mixing would be a slug flow as shown in Fig. 1 (c). This case of no mixing would produce an effluent slug exactly the same as the influent. The slug would move through the tank and maintain its identity

during the entire detention period. Obviously, both the complete mixing and no mixing cases are limiting ones not attained in practical tanks.

The slugs in an actual continuous flow tank will not remain as slugs nor will they be completely mixed. Studies of actual flow conditions are available from investigators working on sedimentation problems.

SETTLING:

The purpose of a continuous-flow settling tank is to promote conditions as nearly quiescent in a vertical section as is compatible with the flow. The optimum case is movement through the tank with uniform velocity. Hence, the ideal settling tank would be one in which the flow is exactly the same as the limiting case of no mixing Fig. 1 (c). Studies in the field of sedimentation have been directed at the elimination of mixing since good settling is not produced with turbulence. A review of the characteristics of sedimentation tanks may help to amplify the present problem.

A contribution in the field of waste-water sedimentation was made by Camp (6) in studies of continuous-flow tanks. Similar studies have been made by Fair and Geyer (14) and others. These studies indicate that some inflow to a continuous-flow tank reaches the outlet in less time than the theoretical detention period. Other portions reach the outlet later than the theoretical detention period. Essentially the addition of a slug to a sedimentation tank produces a resulting outflow concentration which increases before the theoretical detention period, reaches a maximum near the theoretical detention period, and than slowly diminishes. Such a curve would be similar to Fig. 1 (a). Camp studied this characteristic for a number of

different tanks and was able to reach some conclusions as to the optimum shapes to produce uniform velocity and good settling. The best settling was obtained in tanks which were long with respect to width, such as a round-the-end baffled mixing chambers. Next were long and narrow tanks, followed by wide and relatively shallow rectangular tanks. Radial flow tanks produced the poorest stability with regard to unifrom velocity.

EQUALIZATION:

An effective equalization tank must accept a shock load and covert it into a uniform effluent concentration. The degree of reduction in concentration should depend on the flow-through characteristics of the tank. Since the centroid of the dimensionless flow-through curve defines the detention period, a uniform effluent curve would have a base equal to 2T. Then for a total area of unity, the constant ordinate would be 1/2V. This represents a value of 0.5 for the ratio c/C_o as shown in Fig. 1 (d).

It can readily be seen that the requisite flow-through conditions for equalization are quite apart from those for settling or mixing. While equalization requires a constant effluent concentration, mixing produces a continually decreasing concentration and settling tanks result in markedly peaked values. Inefficient tanks designed primarily for mixing or settling would produce flow-through curves tending toward the shape required for equalization. Thus, the use of settling and mixing tanks for equalization depends on their inefficiency for their primary function. It would appear that more effective results could be obtained in a tank designed especially for equalization.

PROPOSED EQUALIZATION PROCESS

In the previous section some shortcomings of the use of settling or mixing tanks for equalization were discussed. It was pointed out that a complete mixing process would produce a continuously decreasing effluent concentration and an ideal settling tank would produce a significant peak concentration. The effluent pattern suggested for equalization was one of uniform concentration for twice the theoretical detention period.

In order to obtain the desired effluent character for equalization, as shown in Fig. 1 (d), certain criteria for discharge must be met. A certain constant portion of the influent slug would have to enter the effluent throughout the period from zero time to twice the theoretical detention period (2T). Further, one--half of the slug must be released before the theoretical detention period, T, and one-half from T to 2T. The latter requirement is necessary since, by the nature of flow-through curves, the centroid of area falls at T.

TRIANGULAR TANK:

These criteria can be met in a triangular tank of constant depth. Such a shape has been suggested by Kohlschutter (26) for mixing purposes. However, this shape actually meets the requirements for equalization rather than those for mixing. It is of value to compare the flow pattern of the proposed triangular shape with that in an ideal settling tank.

Consider a slug moving through an ideal rectangular settling tank of detention period T. This slug would not appear in the effluent from the

time of injection until time T, when it would overflow as a slug. However, the same type of slug moving through a triangular tank with a weir along one side would have a portion continuously removed. This portion would discharge along with lower-concentration effluent from the remainder of the tank. Mixing in the overflow channel or pipe could result in an equalized effluent.

Fig. 2 displays the proposed scheme. The influent is assumed at constant flow rate with a sudden variation in concentration. This concentration would move through the tank in a slug as shown; however, a portion would continue to leave the tank by the overflow weir. With a uniform velocity in the tank, the rate of removal of the slug would be constant. The amount of the slug remaining at some arbitrary times, t_1 and t_2, is shown in Fig. 2 by the lined portions. The contribution of the slug to the effluent at these times is also shown. Of course, the contribution to the effluent would be continuous and not have the finite width used for illustration. The slug would be discharging at a different place along the weir during its flow through the tank. The weir overflow could continuously be mixed producing a diluted concentration which would remain constant throughout the period of time 2T. The resulting flow-through curve for the tank is suggested in Fig. 2 (b).

PRACTICAL CONSIDERATIONS:

The ideal equalization plan which has been proposed herein is based on a uniform velocity throughout the cross-section of a triangular tank. It is known, from reported sedimentation studies, that uniform velocity is

difficult to obtain in practice. Most practical tanks have some straying currents and short-circuiting. However, by proper design of inlets and outlets, good flow patterns can be obtained. A number of investigators have studied the flow characteristics of the shapes usually used for settling. Since triangular tanks of the type proposed have not previously been reported in the literature, some model studies appear to be justified. The purpose of the latter studies is to determine the degree of equalization efficiency possible in a triangular tank. Further, it would be of value to compare the proposed tank with existing methods of equalization.

EXPERIMENTS

A continuous-flow tank was designed based on the considerations discussed in the previous section. The tank was constructed to permit modifications to the inlet and outlet to obtain uniform velocity. The size was selected to eliminate certain scale effects and was based on reported success with a similar size (30). The description of the tank, experimental procedures and results are presented in this section.

DESCRIPTION OF TANK:

A triangular tank was constructed by placing a wall in a rectangular tank of nominal dimensions two feet by six feet with a two-foot depth. The resulting triangular tank, with base 5 feet and altitude 2 feet, is shown in Fig. 3 (a). The entire tank was made of 10 gauge steel with all seams welded. The tank was provided with supports to place the top of the tank at a convenient level for operation and to install drain lines underneath.

The inlet zone, ahead of the triangular shape, was provided in an attempt to uniformly distribute the inflow. Inflow was through a pipe divided into two legs, the end of each provided with a tee. Thus, the inflow was first divided into four streams which flooded a 4½" zone ahead of a stone baffle. Crushed stone, placed between screens 7" apart, provided a baffle through the entire depth of the tank. Preliminary dye tests demonstrated a satisfactory distribution of flow. The stone baffle proved to be more satisfactory than baffle plates and other devices used. The baffle is shown in the photographs of Fig. 3 (b).

The development of outlet devices resulted in using a series of pipes placed tangent to the flow and near the surface. These were constructed of pipe nipples and tees with an open leg of the tee upward. Into each upward leg a specially made nipple was placed. During preliminary adjustments before a test, each nipple could be adjusted to produce the desired flow from each pipe. The outlets are shown during operation in Fig. 3 (c) and in detail in Fig. 4. By careful adjustment of the nipples, one-sixth of the total flow was discharged at each pipe outlet during a run.

The inflow to the tank was from a high-pressure line through a series of valves and a Rotometer. Various flow rates could be selected by adjustment of valves. A constant-rate pump was provided to enable pumping of tracer into the inflow at the same rate as used for a given experiment.

EXPERIMENTAL PROCEDURE:

A few tracers were considered for use in the tests. Thomas (40) discussed some advantages of radiocative tracers such as their detection in minute quantities. However, special equipment is necessary for handling and measuring the tracer. Salt has been used for many years to determine stream flow velocities (1, 29). Both the sodium and the chloride (39) have been used as the ion for measurement. It has often been claimed that salt has the disadvantage of producing a density current. Various tracers have been compared by Ambrose and Bauman (2) and they demonstrated good results using dye tracers evaluated with a colorimeter.

Preliminary studies were made using chloride as a tracer. The chloride content was determined by the Mercuric Nitrate Method. However, this

technique consumed considerable time since numerous samples were necessary for the construction of complete flow-through curves. In addition, there was no assurance that density currents were not present. For these reasons, chloride was abandoned in favor of a dye tracer.

Fluorescein was selected for use and concentrations evaluated with a colorimeter (Spectronic 20). The technique allowed repeated tests to be made quickly at frequent intervals. Thus, data were collected to plot rather complete flow-through curves.

Dye concentrations of 3 to 4 milligrams per liter were used. Higher dye concentrations in a shock load would diffuse ahead of the flow at low flow rates. Even in still water, high concentrations would diffuse through the tank at a significant rate. Further, it was difficult to reproduce flow-through curves when sudden shock loads of dye were injected. The duration of time required to inject the dye appeared to affect the results. A similar observation was reported by Muszkalay and Vagas (33). These authors found stable results by using a modified tracer technique which was adopted for the work reported herein.

Instead of a sudden injection of dye, the material can be injected for a sustained period into a tank originally containing clear water. Conversely, a tank initially filled with dye could be subjected to a continuous flow of clear water. Consider the former case with injection into a rectangular and a triangular tank. Flow-through curves for these cases are shown in Fig. 4 (a) and 4 (b) respectively. Dye continuously pumped into an ideal rectangular settling tank, which initially contained clear water, would not appear in the effluent until time T. Thereafter it would continue to

discharge at a constant concentration. In a practical settling tank, the dye would first appear sooner and rise to the constant concentration. This rising portion of the concentration - time curve describes the flow characteristics of the tank (33).

Dye pumped continuously into a triangular tank, with outlets as proposed herein, should produce a flow-through curve as shown in Fig. 4 (b). Here, some dye would immediately appear and continue to build-up in the effluent in a linear manner. Therefore the case of ideal equalization would appear as in Fig. 4 (b) using the modified tracer procedure.

Instead of continuously pumping dye into clear water, clear water could be pumped into a tank initially filled with dye. In this case one could interpret concentration as the proportion of clear water. Then the flow-through curve should also appear as presented in Fig. 4 (b). This procedure was employed in most of the tests since it provided some advantages. Dye did not appear to diffuse against the flow and hence gave a more accurate trace of the flow. Further, lower initial dye concentrations could be used which also reduced diffusion ahead of the flow. Both problems were apparent in tests where dye was pumped into the tank.

In summary, the basic procedure used in most tests was to initially fill the tank with water containing a known dye concentration. Clear water was continuously pumped into the tank and samples taken from each outlet. These samples were tested for dye concentration and then blended equally for a composite concentration. The resulting data were used to construct flow-through curves. A more detailed discussion of the procedure employed for each type of test is presented in the following section along with the results.

RESULTS OF EXPERIMENTS:

The first series of tests was made using the procedure of pumping dye into the tank. This was done by initially running clear water through the tank at a known constant rate. Dye, of known concentration was then pumped into the tank instead of allowing clear water to continue to flow. The rate of flow of the dye solution was made exactly the same as that of the clear water by pre-setting a variable-speed pump to the desired flow rate. Thus, the flow of clear water was suddenly stopped and dye solution injected at the same flow rate.

Immediately after beginning to pump dye, samples were taken at each effluent pipe and their concentration determined. In addition, the concentration was obtained from a blend consisting of equal portions taken from each outlet. The sampling was repeated at frequent intervals of time and continued until the concentration of dye became extremely low.

The pumping of dye was continued for definite periods of time before clear water was again admitted to the tank. The results for periods of dye pumping of 12, 18 and 38 minutes are shown in Fig. 5. These data were obtained for a flow rate of 2.25 liters per minute with outlets adjusted to remove liquid from the surface. Equal flows were obtained at each of the six effluent pipes shown in Fig. 3(c). It should be noted that the flow into each outlet was not equal; but, it was the total flow at each effluent pipe that was made equal to one-sixth of the total flow.

The effects of various depths of outlet submergence were also studied using the technique of dye pumping. The pipe nipples which extended to the

surface from each tee were removed. The pipe line containing the tees was rotated 180 degrees and nipples of various lengths were provided. The effluent was therefore taken from various depths upward through each nipple to the pipe line and thence to the effluent. Again, the flow from each line was adjusted to one-sixth of the total flow. Fig. 6 presents data obtained from outlets of various depths at a flow rate of 9 liters per minute. Dye was pumped for 4 minutes in each test. The ordinates were obtained for Fig. 6, as well as Fig. 5, by dividing the concentration, c by C_o. In this case c represents the blended concentration from the six effluent pipes and C_o the concentration computed from the total weight of dye pumped divided by the tank volume of 207 liters.

A second series of tests was made employing the alternate technique of beginning with a tank initially filled with a dye solution of known concentration, C_o. A flow of clear water was then started and effluent measurements taken at each of the six points and on a blended sample. Seven runs of this type were made using surface outlets and a flow rate of 4.5 liters per minute. The results of these tests are shown in Fig. 7. Here the time is presented as a ratio of the time to the theoretical detention time computed from the tank volume and flow rate.

DISCUSSION OF RESULTS

The effects of the duration of time that the dye is pumped appears to significantly influence the interpretation of flow-through characteristics. It can be noted in Fig. 5 that the peaks for each curve differ and that this difference is about equal to the differences in pumping duration for any two curves. Of course, the pumping durations varied widely. However, the point raised by Muszkalay and Vagas (33) concerning the importance of pumping duration is demonstrated by these results. This point has been discussed previously.

In addition to the variation due to pumping duration, stability was a problem at any given rate. It was noticed that when high dye concentrations were pumped, dye would diffuse ahead of the flow. High concentrations were necessary in order to get suitable concentration readings at short pumping durations. In order to avoid the diffusion, lower concentrations were pumped for longer durations. However, in these cases a thin film of dye appeared to concentrate at the flow surface.

Various outlet depths were then studied to determine the effect on flow characteristics. It is shown in Fig. 6 that, all other conditions equal, the depth of withdrawal affects the flow pattern. The surface outlets appear to have been more condusive to short-circuiting than, for example, those placed at a depth of 3/4 inch. This is apparent by the displacement of the mode in Fig. 6. A theoretical detention time of 23 minutes was extant for the tank. The seven-inch depth provided the best results in this series. There was serious concern in these later tests

as to the problem that the results still were not representative of the flow pattern. The pumping of dye, which required high concentrations, still caused apparent diffusion ahead of the flow. For this reason, the alternate testing technique was developed which employed a tank initially filled with dye solution.

Preliminary tests in the second series indicated that surface outlets were equal in performance to the others. Further, there appeared to be an optimum flow rate for stability and reproduction of data. Since low initial dye concentrations could be used, there was no serious problem of diffusion against the flow of clear water. The results of seven tests are presented in Fig. 7. The solid line represents the theoretical or "ideal" equalization as proposed herein. Thus, the test tank, when used in its region of useful flow rates, provides a good degree of equalization.

CONCLUSIONS

It has been demonstrated in this work that:

(1) Dye tests must be selected carefully to obtain results which reflect the actual flow characteristics of a tank.

(2) Tests which employ a tank initially filled with dye of low concentration provide the advantage of minimizing diffusion of dye ahead of the flow as when dye is pumped.

(3) There is a flow rate for a given tank which provides maximum flow stability.

(4) Within its optimum flow rate, a triangular tank as proposed herein provides a good degree of equalization.

(5) The proposed tank could provide a simple and practical solution to the problem of shock loads in domestic and industrial waste--treatment plants.

NOTATION

c	effluent concentration at time t
C_o	average concentration, W/V
Q	flow rate
t	time
T	theoretical detention time, V/Q
V	volume of tank
W	weight of material in slug

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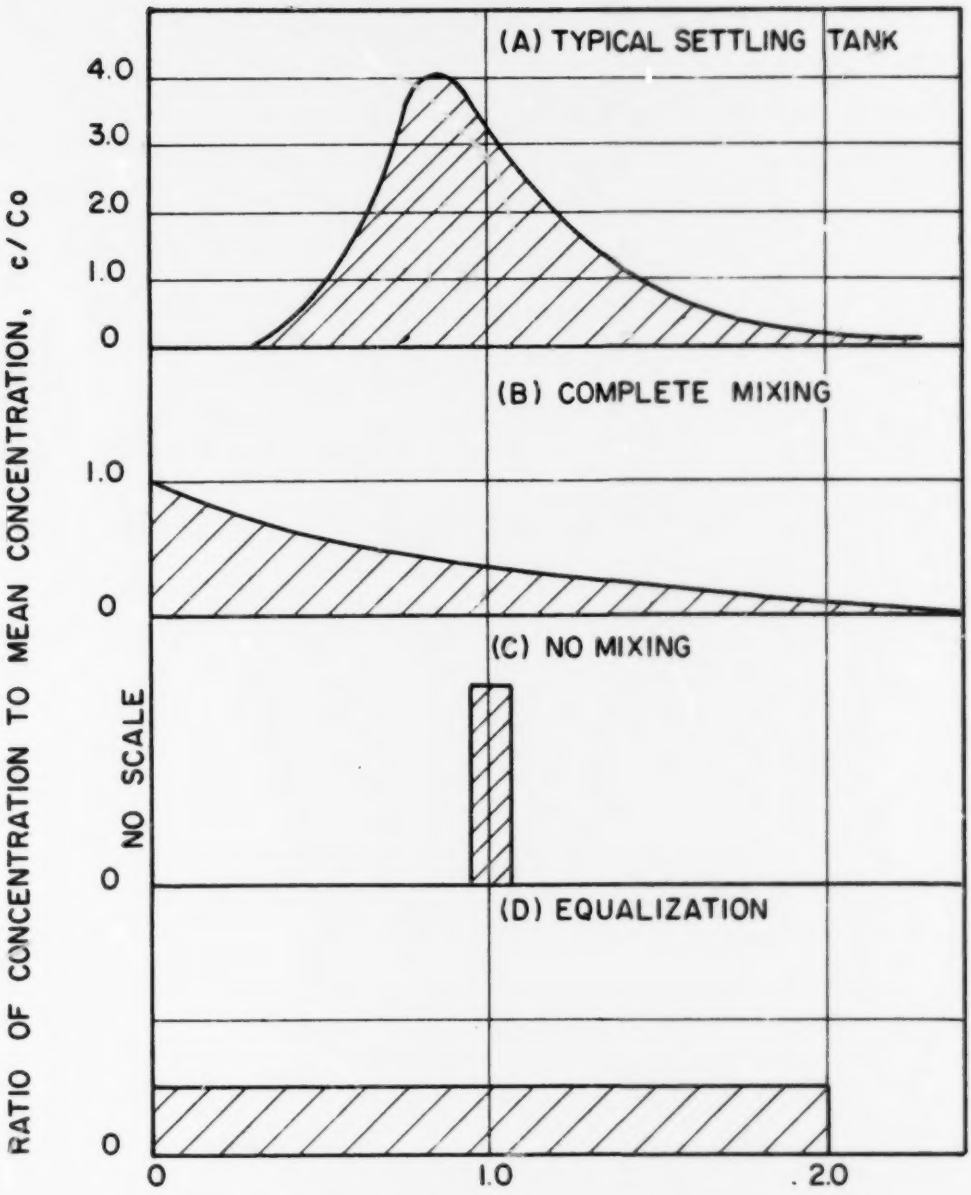


FIGURE 1 - FLOW THROUGH CURVES FOR CONTINUOUS-FLOW TANKS

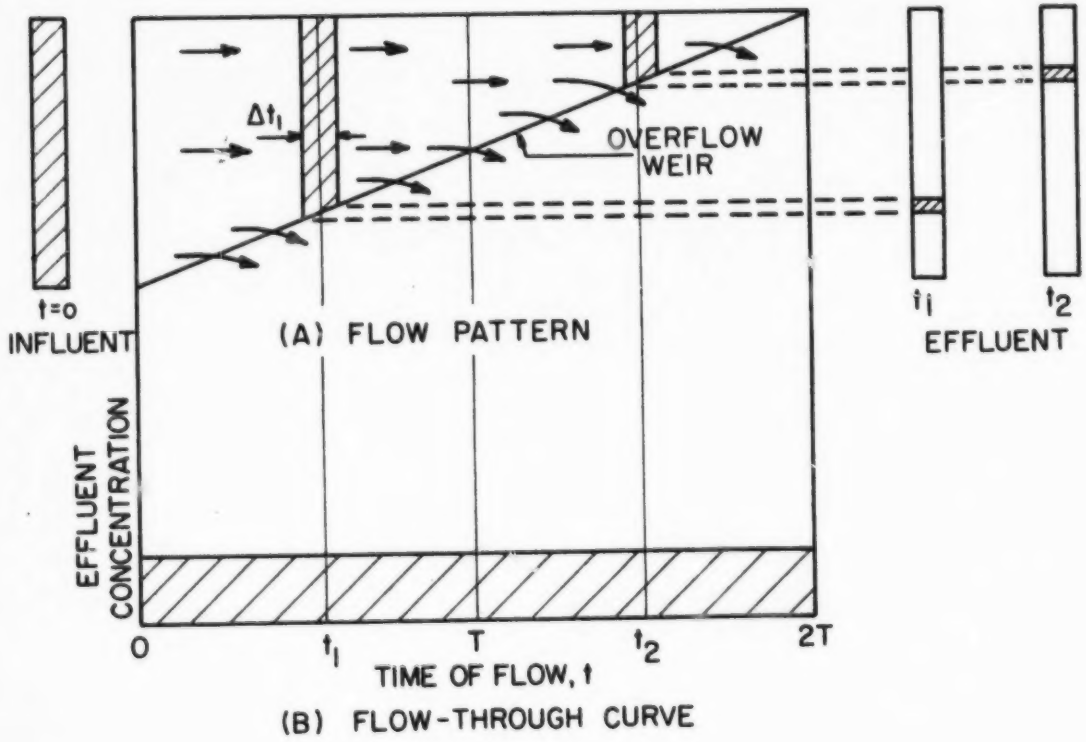
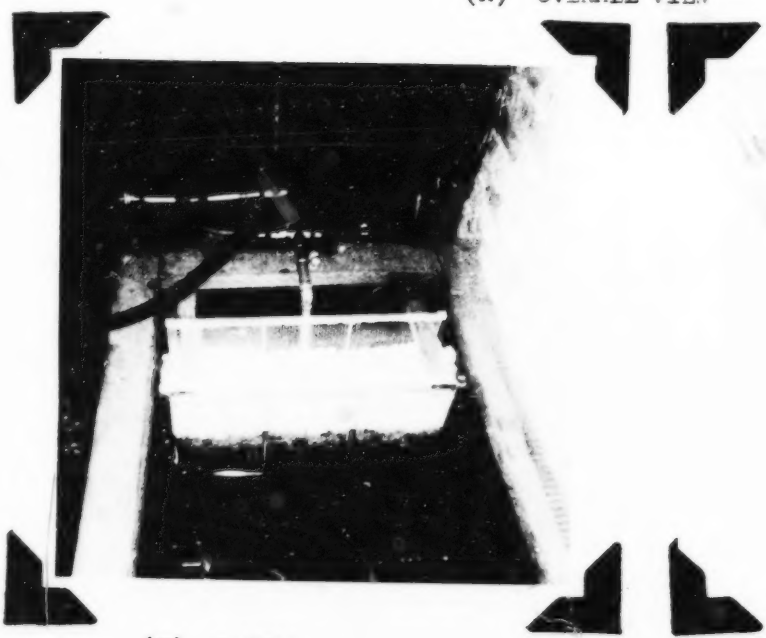


FIGURE 2 - EQUALIZATION IN A TRIANGULAR TANK

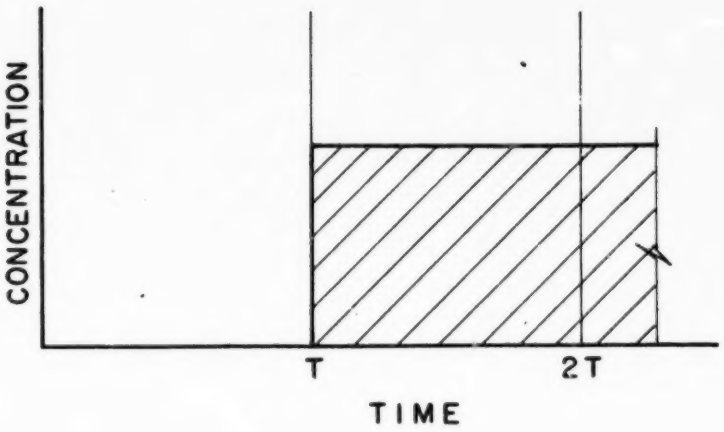
(A) OVERALL VIEW



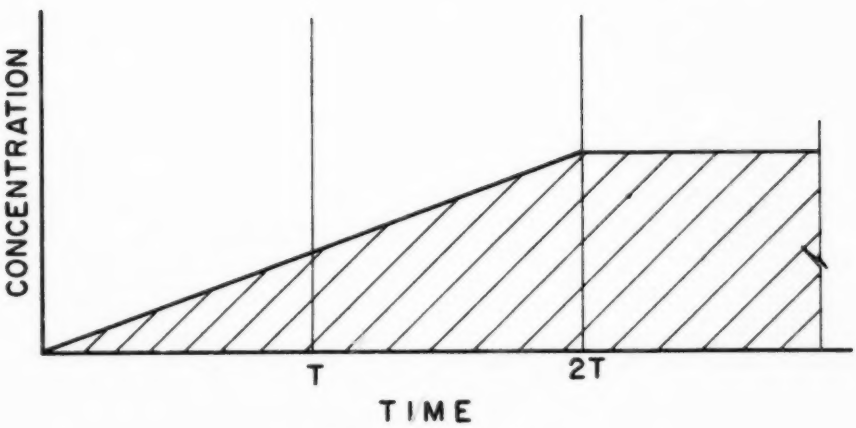
(B) BAFFLE

(C) OUTLETS

Fig. 3 EXPERIMENTAL TANK



(A) RECTANGULAR TANK



(B) TRIANGULAR TANK

FIGURE 4 - IDEAL FLOW-THROUGH CURVES FOR MODIFIED TRACER TECHNIQUE

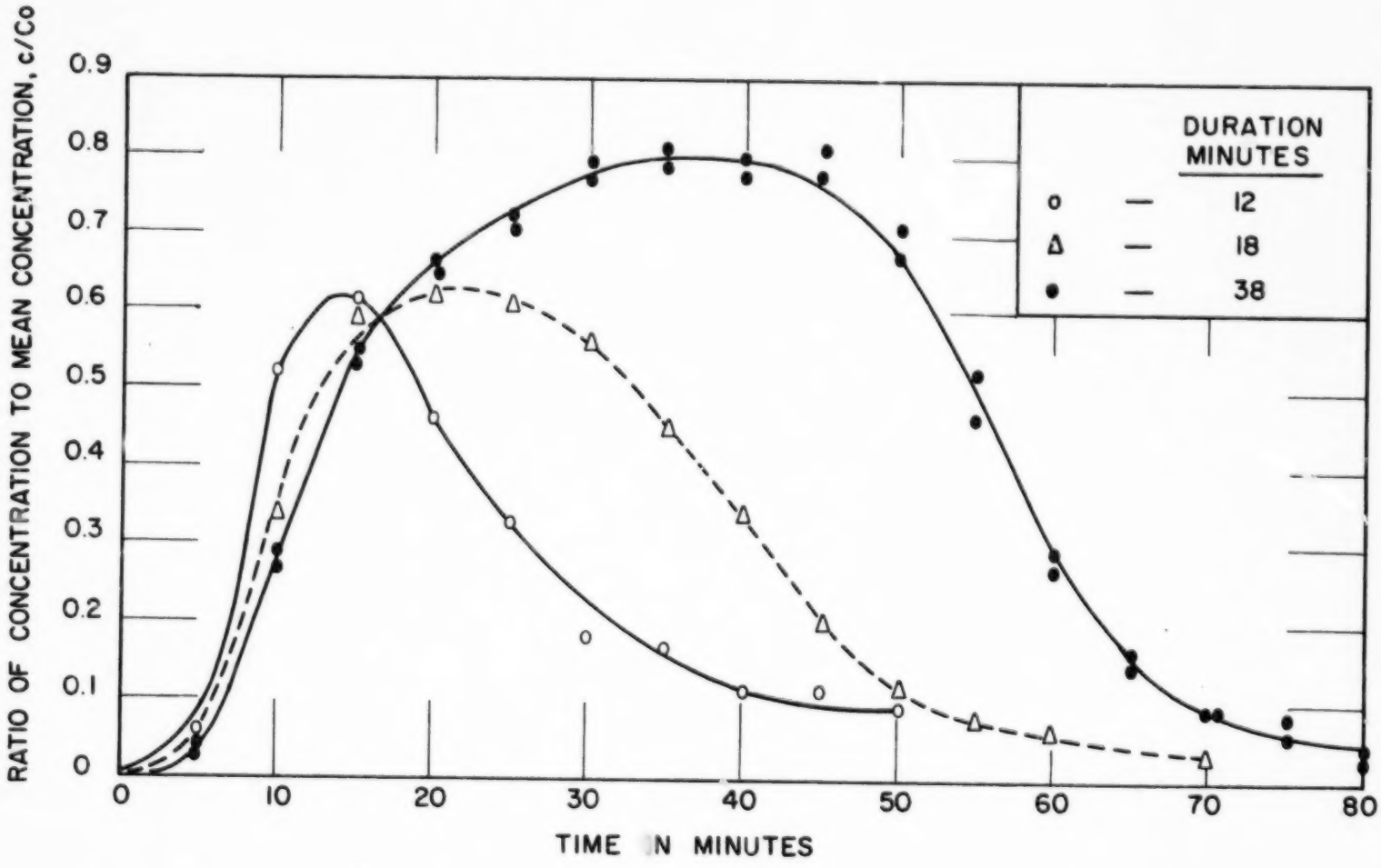


FIGURE 5 - EFFECT OF DURATION OF DYE PUMPING

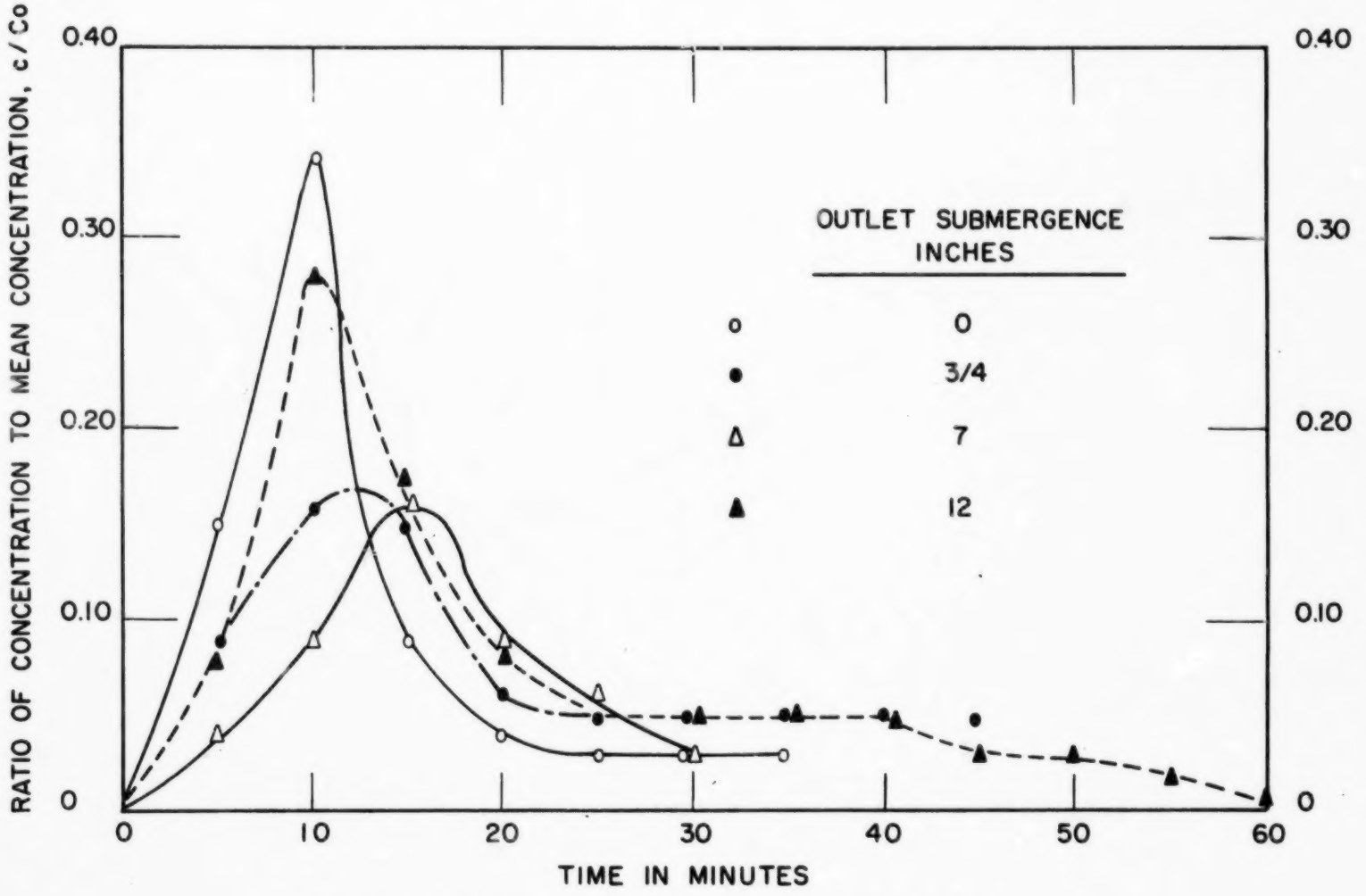


FIGURE 6 - EFFECT OF OUTLET SUBMERGENCE

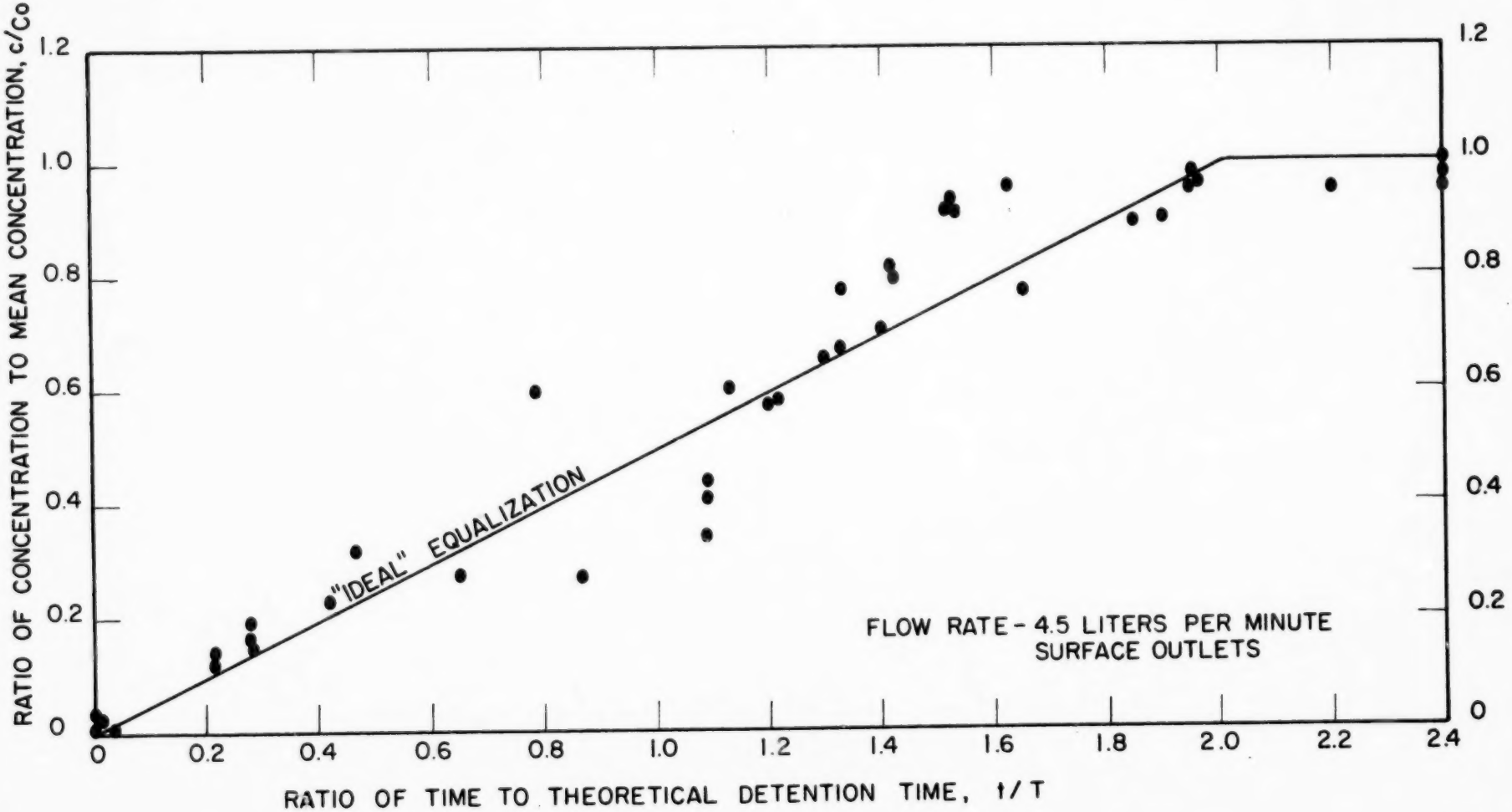


FIGURE 7 - FLOW CHARACTERISTICS OF MODEL TANK